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Annu. Rev. Earth Planet. Sci. 1999. 27:1–17

UPS AND DOWNS IN PLANETARY SCIENCE

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KEY WORDS: Gene Shoemaker, moon, impact, comets, Australia

ABSTRACT
The field of planetary science as it developed during the lifetimes of Gene and Carolyn Shoemaker has sustained a period of exciting growth. Surveying the skies for planet-crossing asteroids and comets and studying the results of their impact upon the planets, especially the Earth, was for Gene and Carolyn an intense and satisfying quest for knowledge. It all started when Gene envisioned man going to the Moon, especially himself. After that, one thing led to another: the study of nuclear craters and a comparison with Meteor Crater, Arizona; the Apollo project and a succession of unmanned space missions to the inner and outer planets; an awareness of cratering throughout our solar system; the search for near-Earth asteroids and comets; a study of ancient craters in Australia; and the impact of Shoemaker-Levy 9 on Jupiter. The new paradigm of impact cratering as a cause for mass extinction and the opening of space for the development of new life forms have been causes to champion.

INTRODUCTION

It is an honor to be the first woman asked to write a prefatory chapter for the *Annual Review of Earth and Planetary Sciences*. I am intrigued by the idea of addressing a period of scientific development in terrestrial and planetary science along with my own scientific growth. Planetary science as a comprehensive field of endeavor did not exist when I was in the midst of my college studies, but I have seen it emerge as a field that includes areas of every physical science and touches upon some social sciences. It requires an ability to think theoretically and to use skills found in mathematics, computer science, photography, and

0084-6597/99/0515-0001$08.00

mechanics. It challenges the imagination and provides the “stuff” of dreams. To work in planetary science is to work in an area that takes us both back to the origin of our solar system and beyond it into the future.

GENE SHOEMAKER

It is impossible to write about this part of my life without also discussing Gene Shoemaker in a major way. My successes were his successes; what I accomplished was the result of a close and happy partnership for the 46 years we were married. Gene was not only my husband, he was also my scientific teacher, mentor, and collaborator. He was an enthusiastic teacher, who conveyed the excitement he felt in geology, and who instilled that excitement in others. His love of science, of geology and astronomy, was contagious. He was one of a rare breed—a true Renaissance man.

I did not set out to work in science, either as an astronomer or a geologist; I have not had a formal education in either. When I went through college, few were thinking about going to the Moon or even into space. If they did, they wouldn’t admit it. Comets and asteroids were not part of our world, and certainly they did not fall out of the sky. World War II was just over, and veterans flooded the colleges. They were an earnest, sober group, eager to get on with life, to get in and out of school in short order, and my outlook was similar. I was eager to get out and see the world after attending college in my hometown. Four years after I started my classes at Chico State, now known as California State University, Chico, I left school with a master’s degree in history and political science, a secondary teaching credential for high school, and a contract as a seventh grade teacher in Petaluma, California. Then fate took a hand.

Just before I left home to assume my teaching position, my brother married one of my good friends from college, and the best man at his wedding was his roommate at Caltech, a young geologist named Eugene Shoemaker. The first things that impressed me about Gene were his sense of humor and ability to laugh at himself, his enthusiasm for virtually everything, and the energy that seemed to flow from him. Through the following year, while Gene attended Princeton University to work on his doctorate and I taught seventh grade, we corresponded with long letters each month. At the end of this year, I took a two-week camping trip with Gene, who was eager to show me the Colorado Plateau and took me to the most scenic places he knew—there were a lot of them. After the first week, I apparently passed the “love of camping” test. Gene asked me to marry him, and our wedding took place in 1951, exactly one year after my brother’s wedding.

Our Early Years

For the first five years of our marriage, home was Grand Junction, Colorado. Gene, working for the U.S. Geological Survey (USGS), was participating in an exploration for uranium. After the first two nuclear bombs had been dropped on Japan, ending World War II, the Manhattan Project ended. The country had exhausted its supply of uranium, and more had to be found if atomic power was to become a reality. The Survey had contracted with the Atomic Energy Commission to find new sources on the Colorado Plateau, and Gene was involved in running a drilling project and in mapping during his spare time. Individual miners were searching everywhere and “digs” appeared on every hillside. As in all booms, some made it big and some “lost their shirts.” Land scams were the order of the day. It was fun to be on the scene of the last great mining boom in our country.

When Gene went out to map, I went along. Women did not often go in the field in those days, but neither Gene nor I could see a reason why I shouldn’t. For the rest of his life, Gene would champion the causes of women, an attitude he took from his very independent mother. Gradually I began to learn the stratigraphy of the Colorado Plateau and to perceive the many meaningful differences in the shades of orange and red that distinguished the various beds of that area. I was taught all about layer-cake geology in one of the choice regions of the world. I had never thought it necessary to pick something apart to appreciate it, but I was suddenly learning about faults and thrusts, discontinuities and structure; about the difference between sand, pebbles, rocks, and boulders; about what the land had looked like through different ages. Under Gene’s enthusiastic teaching, many of the things that had had no meaning for me in my one geology class in college were becoming fascinating.

In the summer of 1952, Gene and I headed for Nevada and a summer field camp with James Gilluly, a long-time geologist with a heady reputation. To work with him necessitated an ability to be half mountain goat, have the legs and endurance of an Everest climber, have the speed of a greyhound, and have a determination to not be outdone by anyone, least of all by Gilluly. What a learning experience it was for both of us. Newly pregnant with our first child, I could not tag along with the men. Instead, I was camp cook for eight on a regular basis and often many more as they arrived to visit Jim. The stories that were told around the evening campfires opened a whole new world to me.

Three years after we were married, Gene and I headed east to Princeton with our baby daughter, Christy. The chance to run his own program in the search for uranium had been an opportunity too good to pass up, and Gene had taken a two-year break. When it ended, we headed back so he could finish the requirements for his PhD. He completed the Princeton requirements, and we returned to Grand Junction. Gene had been on leave from the USGS and it was time to get back to work. In fact, he was so involved in various projects that he had no time left to write his thesis. It was not until some years later, when the deadline for completing it was running out, that he took the subject that was topmost on his pile of work and turned in one of the shortest and most concise theses in Princeton's history—his work on Meteor Crater, Arizona, which became a landmark paper in cratering studies.

GOING TO THE MOON

In Grand Junction in 1953, Gene first confided to me his dream of going to the Moon. Not just going to the Moon, but being the first geologist, the first scientist, to go to the Moon and—why not?—being one of the first to set foot there. One day in 1948, as a young bachelor new to his job, he had been driving down a canyon road thinking about rocket development during World War II and after, when some of the best German rocket scientists came to work in the United States. Suddenly it dawned on him that during his lifetime man would go to the Moon. He planned to be ready, to be the most knowledgeable and best-prepared person when that time came. I was truly startled, for when he told me this it was a time when *no one* had such aspirations, because no one envisioned such a thing happening. I knew this wouldn't happen immediately, and like Gene I didn't discuss the subject with anyone else—but I wondered if I could go along. From the day he told me of his desire, I started looking at the night skies with much more attention.

Christy, Patrick, and Linda, our three children, went out in the field with Gene and me from very young ages. Field life was a regular, enjoyable part of our existence. Gene, above all, was a field geologist who enjoyed the challenge of reading the rocks and understanding the history they told. Field work to him was more a vacation than a job because he enjoyed it so much. He shared this passion with me, explaining all he could wherever we went.

In the fall of 1957, our family of five went to the Hopi Buttes for some mapping with two other geologists, Frank Byers and Carl Roach. Gene had found uranium in the Hopi Buttes, and further geological mapping of the Navajo and Hopi country was needed, with attention to diatremes (exploded volcanoes). One evening, upon returning to our camp on the Navajo Reservation near Indian Wells, we were told by Frank and Carl that the Russians had put up a spacecraft. Sputnik triggered a major change in our lives. Gene was dismayed by the Russian achievement; he knew that it would spur the United States to start its own space program before he himself felt ready to participate. He had his work on Meteor Crater and also the nuclear craters at the Nevada test site to finish first. Nevertheless, henceforth, he never deviated from that ultimate goal of participating in a space program that would fulfill his dream of lunar exploration.

From 1957 to 1960, Gene's research was directed toward the structure and mechanics of meteorite impact and nuclear explosion craters. In studying the latter, he could see the close relationship between the two types of craters. As he pointed out to me when we looked through his alidade at the Moon, a study of craters was necessary to understanding what man would be looking at there. His work on Meteor Crater, Arizona, led to the discovery with E.C.T Chao of coesite, a high-pressure form of silica not usually found in natural features on Earth. Coesite was a tool that indicated an extraterrestrial impact. I was impressed when we went to the Ries Basin in Germany, before the 1960 meeting of the 21st International Geological Congress in Copenhagen, to see Gene descend briefly into a quarry and return with samples he expected to contain coesite. He dispatched them by air to Ed Chao, who promptly analyzed them in the USGS lab in Washington, D.C. and found coesite. Sure enough, this diagnostic system using coesite was proving true to Gene's hopes for it!

Our family was living in Los Altos, California, by 1959, having moved there when the USGS program with the Atomic Energy Commission for finding uranium came to an end after the discovery of vast new resources in New Mexico. Gene elected to join the Menlo Park office of the USGS instead of moving to Denver. With his thesis completed, Gene began studying the Moon in earnest, and at last we could "come out of the closet" and talk openly with a few other young geologists there about his goals for going to the Moon. In 1961, President Kennedy made his famous pronouncement about going to the Moon and back. Gene and I followed each advance of man rocketing into space with the Mercury program, and we avidly consumed all the details released by the press.

The year of 1960 was eventful. Gene traveled constantly, pursuing the establishment of an Astrogeologic Study Group within the USGS. The USGS is an old conservative organization and to establish such a group was not easy. The Survey's charter was to study and investigate the geology of the United States and sometimes aid studies in other countries; "old-timers" were not eager to risk, as they perceived it, their careers on a truly "lunatic" idea and transfer into astrogeology. I yearned to hear more about the program, but with young children to tend to, I had to be content with following its progress whenever Gene was home to tell me about it.

Planetary science was in its infancy. Astronomers had long since left the solar system to study the universe, but geologists, literally, could hardly get off the ground. After the first group of seven Mercury astronauts had been selected, followed by a second group of nine Apollo astronauts, a third group was to be chosen. Gene was not so naive as to think there might be a scientist among them. Military pilots were the choice of NASA. In the fall of 1962, we moved to Washingtion, DC, so that Gene could work with NASA as Acting Director of the Manned Space Sciences Division. The move plunged us into the frenetic scene of the political arena. With the development of manned space flight, NASA was growing rapidly into a large organization. Gene could not, would not, imagine that the American public would be satisfied to go to the Moon just to beat the Russians there. The time had come to think about a real purpose for man to go into space; the selection of the science astronauts was about to occur.

Any other year, Gene would have applied to be an astronaut, but in 1962, he gradually became very ill. As the year advanced he saw one doctor after another, hoping for a diagnosis. After almost nine months, we finally learned that his adrenal glands were not functioning (a condition known as Addison's disease), and his bodily functions were shutting down. Once the diagnosis was made and supplementary cortisone prescribed, Gene made, within a couple of days, a miraculous recovery. Because blackouts were a common symptom associated with Addison's and because most people with the disease died before cortisone was discovered, he knew that he could never pass the stringent physical examination required of astronauts. Instead, he accepted the position of Chairman of the National Academy's Science Astronaut Selection Committee. It was now necessary for him to put aside his earlier dreams of going to the Moon; he had to do his best to make the space program work for other astronauts.

In 1963, with the organization of the Branch of Astrogeology, the family moved to Flagstaff, Arizona, where the space age would come to fruition for us. Flagstaff, which was a proven site for astronomical observing, was an ideal place for a small telescope (31 in) dedicated to studying the Moon, and in addition, nearby Meteor Crater and the craters of the San Francisco Peak volcanic field afforded valuable comparisons with the lunar landscape. There was much to learn before the astronauts arrived on the Moon.

Now came the years of extensive travel for Gene, as he developed a lunar geological time scale and suggested methods of geological mapping of the Moon. He became involved in the application of television systems to the investigation of extraterrestrial geology, taught courses in astrogeology at the California Institute of Technology, and served as coinvestigator of the television experiment on Project Ranger, principal investigator of the television experiment on Project Surveyor, and principal investigator of the geological field investigations in Apollo lunar landings from 1965–1970. He was Chief of the USGS Branch of Astrogeology until 1966 and then, in a shift from administrative work to scientific studies, became its Chief Scientist until 1968. One of his many projects was to institute the geologic field training of the astronauts who would go to the Moon and to take them to various sites throughout the world.

Another project was to learn to fly an airplane, on the premise that he could demonstrate how much more easily a scientist could learn to fly than a pilot could learn science. When he could not pass the medical exam required of pilots because of his Addison's, he encouraged me to get my own pilot's license, and we flew together.

A SHIFT IN COURSE

During all this time, as our children grew to their teens, I was a homemaker and entertained the seemingly infinite number of scientists who passed through our doors. Gene kept me abreast of developments in the space program as much as possible, and the many visitors also helped to maintain my interest in that program.

Then, in 1969, our family shifted course. Gene had become tired of the infighting involved in the space program and felt that the scientific goals would never come to pass. Only one scientist, geologist Harrison Schmitt, had been selected to go to the Moon. Gene was away from home three quarters of the year and was exhausted. Also, as our children entered high school he knew the family would need him. Leaving the Geological Survey, he took up the position of Chairman of the Division of Geological and Planetary Science at Caltech, and we moved to Pasadena, California. Unfortunately, the Apollo program had been set back one year after the fire in Apollo I, and Gene was still committed to work on another Apollo flight even as he took up his new responsibilities.

Caltech was a new experience for me. I had never encountered such a concentration of scientific, intelligent, single-minded prima donnas! I was fascinated to realize that not only were the professors, researchers, and students extremely capable and dedicated, they also loved their research as much as Gene did his. I enjoyed this atmosphere, although while our children were still at home finishing high school and going off to college I was not yet ready to take part in it.

At Caltech, Gene went on to become a coinvestigator with the television experiment on Project Voyager. This occupied much of his attention from 1978 to 1990. Now there was a mission! I shall never forget walking over to the Caltech campus, where, on a large screen in Beckman Auditorium, images of the Jupiter flyby were being displayed as they came in. Then and there, I fell in love with planetary science, the skies, our solar system, and the universe. I was excited and captivated. Exploration of the Moon during Apollo days had been vicariously, for me, a heady experience, but the idea that *I* could look at Jupiter and its moons in something like real time left me awestruck.

The First Palomar NEO (Near-Earth Object) Search

In 1973, Gene initiated the Palomar Planet-Crossing Asteroid Survey with Eleanor Helin. After studying craters on Earth and the Moon, then on Mercury and Mars, he became convinced that cratering was a fundamental process in the formation of our solar system. A look at all the craters on some of the moons of Jupiter—Europa, Ganymede, and Callisto—helped to confirm his belief that cratering by asteroids and comets had occurred on all the solid bodies of the solar system. Yet there were almost no statistics on the numbers of planet-crossing asteroids and comets, much less Earth-crossing bodies. He would have to obtain the statistics at the telescope, and Eleanor Helin was interested in taking part. Eventually a search program on the 18-in Schmidt telescope at Palomar Observatory, owned and operated by Caltech, was established. As it turned out, this telescope (really a camera), the oldest and smallest at Palomar, was the best telescope in the world for the search. With its wide-field view, one round, 6-in-diameter film covered 60 square degrees of sky. In the ten years of that survey, with the help of many students, techniques of observing were gradually developed, and the team began to find asteroids that crossed Earth's orbit. Still, the discovery rate was not high, and Gene hoped to develop "cheaper, better, and faster" methods, to quote a phrase current today.

BECOMING INVOLVED

By the late 1970s, our children had grown and left home. I felt a need to do something interesting. I wanted to find some area of strong compelling interest—something that would absorb my time and energy and stimulate the thinking process. When Gene proposed the idea of working with him on either his paleomagnetic projects or the search for Earth-crossing asteroids, I replied that I "had done the paleomagnetic bit" but would like to try working on the asteroid search.

In the beginning of this work, I went with Gene to his office at Caltech and started helping there. Then, on a somewhat casual basis in 1980, I started to search for asteroids on the large plates, 14 × 14 in, that were taken on the UK Schmidt telescope at the Siding Spring Observatory in Australia. Bobby Bus, at that time a Caltech student, was my teacher first in scanning and later at the telescope. He taught me how to scan the large glass plates on a blink comparator and to measure the positions of asteroids in the sky. He was meticulous in this work and showed me the importance of doing each step carefully. Because he was patient with me, I found the asteroid work enjoyable.

Gene, in the meantime, had concluded that the discovery process would be easier and faster with a stereomicroscope. This was a procedure that was originally developed by Max Wolf in Germany during the 1800s, but Wolf could not see stereo and so did not use the new system for long. Now Gene hoped that a stereomicroscope built especially for use with the films from the 18-in Palomar telescope would speed things up. Together with Helin, he had one made to their specifications by a company in California, which completed it in 1980. Up to that point, Helin had used a monocular microscope with success and was apparently not eager to try this system when it arrived. Gene, by then, was spending half the year at the USGS in Flagstaff and half the year at Caltech. When we returned to Pasadena for the winter quarter, he found that Helin was not using the microscope. A student who had been working with her had tried it out and was not very successful in finding any asteroids. Dismayed, Gene tried looking at films himself and then asked me to try. Neither of us had difficulty in seeing the asteroids, and we decided to experiment with the system further. When we returned to Flagstaff, we took the stereomicroscope and some 18-in films with us, set the microscope up at home, and commenced a search. We had fun as we sorted through thousands of stars, dust, scratches, and other marks on the films. In short order, once he knew that I could find asteroids, Gene left the scanning of films to me. As the years passed, the search for asteroids, and later comets, would increasingly become my particular project.

Back at Caltech, I learned to observe at Palomar Mountain Observatory. Because I am a morning person, I had real doubts about my ability to observe through the night; I had never stayed up all night in my life. I thought that I might have to be content with scanning the films others had taken for me. Nevertheless, I resolved to try observing. Sleep deprivation while observing was, in fact, a real problem for me in those first years. We would finish a night's observing and go to bed when the birds were beginning their early morning songfest; two or three hours later, I would wake up. However, as I learned the ropes—taking 10- and 20-min exposures and guiding on stars with an often cranky telescope; learning the method of developing the films and the procedures of recording information on the margin of films, bagging the films, and recording the observations in a notebook for Palomar and another notebook for us; and learning methods of planning nightly observations—and as I had more practice in scanning the films with the stereomicroscope, I found a real joy in going to the mountain. I would sit guiding at the telescope and find myself marveling that *I* was actually observing at *Palomar*. This was an observatory I had heard of during much of my life; I had visited it with my parents as a child at the time the 200-in telescope was newly completed and installed. To be sure, the 18-in was not a glamorous telescope in a world where "bigger" equates with "better," but I had a growing fondness for that instrument.

The Second Palomar NEO Search

In 1982, Gene and I started the Palomar Asteroid and Comet Survey (PACS) and started observing together for the first time. Helin had developed her own program separately and the two projects parted company. In the ensuing years, both projects used the 18-in at one end or the other of the “dark run,” the two-week dark-of-the-moon period each month centered on the new moon. Gene and I decided to observe for seven nights each run, figuring that we should have at least four nights of good weather, which would enable us to take lots of fields. Soon, using a spectrographic film called Kodak IIa-D, we started taking 4-min as opposed to the earlier 10-min exposures. That was something to keep me awake! With only the two of us observing together, there was no time for anything else. We traded jobs on the telescope, one of us taking the first half of a set of four or five fields, and then the other taking the second half of identical fields. Whoever was not actually guiding the telescope helped first to position it on a field by providing the coordinates and recording times on the log sheets; then that person would rush downstairs to the dark room, change the film to a new one, and run back upstairs in time to start the process all over again. If we wanted a snack or a cup of coffee in the night to keep up the energy level, we would have to grab it on the fly. Our interest lay in photographing as much of the sky as possible; one long night we managed to expose 96 films between evening twilight and dawn, but we were really dragging by the end of the night. Throughout our program, we would take two exposures of the same field about 45 min apart. Placing a pair of films side by side on the stereomicroscope made it possible to detect the asteroids and comets by stereopsis as “floating” objects against a background of stars. The parallax, caused by the movement of the Earth during the time difference in the taking of the films, allowed us to see such nearby objects without the necessity of blinking the films, which was the more commonly used method of search.

One day in 1987, Alain Maury, then at Palomar, stopped by the dome. He told us about a new film, Kodak’s Technical Pan 4415, which we could use if we would hypersensitize it to speed up the emulsion. This would allow us to take 8- or 10-min exposures with the Technical Pan rather than the 1-h exposures that this film would otherwise require to obtain images. We would no longer be able to take 4-min exposures, but we would improve our ability to find asteroids or comets because there was virtually no grain observable. We would be able to see the really faint (18 to 19 magnitude) asteroids. So we learned to hypersensitize our film for 6 h at 65°C with forming gas (a mixture of hydrogen and nitrogen) flowing through the boxes in the oven. We found more asteroids, took fewer films, and relaxed slightly. Use of the new film allowed us to develop most of the exposed films during the night, leaving more time in the day for “cutting the cookies,” as we called the round pieces of film, hypering, and doing all the other things that were a regular part of observing.

I found that scanning films became easier and faster the more I practiced. Not everyone can see in stereo, as I learned when I worked with Caltech students. Fortunately, I had no difficulty with this and soon could find most of the interesting objects on a pair of films within 20 min. That is not to say that I didn't miss some, but they were usually faint, out of focus, or only on one film, with the second image mostly hidden by a nearby star. Sometimes I would become sleepy while scanning and realize when I finished a pair that I couldn't remember marking any asteroids. That was a signal to get up, move around, develop films, observe, or go outside to walk around the dome and just look at the sky. I gradually stopped seeing the artifacts (dust, scratches, other marks) in favor of seeing asteroids and comets, but more time passed before I started to see displaced images. Because we looked at negatives, most asteroids appeared as a single floating point of light in the form of a little black ball. The faster motion of some of these objects gave them a separate appearance, so that I saw two black balls, or two hyphens if the object moved even faster within the 8-min exposure. I learned about retrograde and prograde objects, which under the microscope would either float or sink, respectively. At first I saw only the bright objects, but with time I saw fainter and fainter objects. The search was fun, and when I discovered my first near-Earth asteroid, 1982 RA, I was thrilled. For the first time I noticed little hyphens, widely separated, instead of little floating balls, and I added short and long hyphens to my repertoire of things to look for.

Comets sounded exotic to me, and I wondered if I would be able to see any. The first comet I saw on our films was one I deliberately searched for according to the predicted position; it was Comet Bowell (1982 I). It was a unique comet because its coma was the result of one outburst of dust. It was well beyond the orbit of Jupiter when I saw it, a faint, fuzzy image on one film and scarcely brighter on the other. After that I was discouraged because it seemed impossible that I would ever discover a new comet. By the fall of 1983, however, I had seen a few other comets on our films.

A NEW COMET

One day in late 1983, I was scanning films at the USGS in Flagstaff in an effort to catch up with all that we had taken on a fairly good observing run (I was never able to scan all the films at the observatory). Suddenly, there it was! The image of a comet that I thought might be new. I ran from the little room where I scanned films at the back of the library down the hall to a phone in Gene's office and called Brian Marsden. He is Director of the Central Bureau for Astronomical Telegrams (to which all new discoveries are reported from around the world). Giving him approximate positions for the comet, I waited anxiously for him to tell me if it was new. Marsden checked his files and reported to me that this was, indeed, a new comet. A feeling of elation swept over me, one which I was to feel later with each new comet discovery. Each comet has a unique appearance on our films, so each new discovery is a new experience.

From the moment I found Comet Shoemaker 1983p, as it was designated, my interest in comets increased rapidly. There was a lot to learn about them, and one of the particular areas of study was a growing awareness of the role they play in impact throughout our solar system. Gene felt strongly that comets are responsible for the abundance of water and other elements necessary for life as we know it, that we may truly be made of comet "stuff." Comets were added to our search program, and by the time PACS came to an end in December, 1994, I had found 32 of them, 27 with Gene.

After we accidentally found our first Trojan asteroid, we started a special search for them. Trojan asteroids have been captured into the 1:1 resonant areas known as the Lagrangian equilibrium points of the Sun-Jupiter system; they comprise two swarms on either side of the giant planet, where they are held at a distance safe from capture by Jupiter and from which only a few have been observed in the process of slowly escaping. Gene calculated the numbers of Trojan asteroids in the two swarms and concluded that there should be many sufficiently bright enough for us to discover. The search for Trojans presented a new challenge to me. They are sufficiently far away from us that their parallactic displacement is small. That means that on our films, taken with fairly short intervals between exposures, Trojan asteroids hardly appeared to move at all or, in so many words, would barely "float" in stereo above the background stars. I had to develop a different perception of depth as I looked for them.

With us on that first search for Trojan asteroids, in 1985, was Richard Preston, a young, aspiring author who had come to Palomar to write a book about the 200-in telescope. We first met him at the dining table of the Monastery, which housed most of the astronomers during their observing runs at Palomar. We suggested that he come to the 18-in telescope some night to see how "real" or "old-fashioned" astronomy was done. This resulted in a nightly visit on that observing run and a request from him to come again. He was intrigued with our proposal to search for Trojans, and it was through his persistent urging that I finally took a hard look at the films for these objects. In succeeding years, we continued to search for them and ultimately discovered 47 new Trojans. From this search, we learned that the two swarms together probably contained as many as half the number of asteroids in the main asteroid belt between Mars and Jupiter.

By 1987, I was searching our films for "high floaters" (near-Earth asteroids) and "low floaters," those that seemed to be below the plane of the background stars, as though in a hole (very near asteroids), "displaced hyphens" (Earth or Mars crossers), fuzzy images with or without tails (comets), and, lastly, the "very low floating images" of Trojans. I was on the trail of unusual moving objects. Sorting all of these out from the thousands of images of stars on the films, along with measuring their positions in the sky with evolving techniques, kept me busy—I could work on the PACS project every waking moment, if I wanted, and enjoy it.

Looking at films was a little like looking out of a spaceship window; I was transported out into the universe where I could see galaxies, star clusters, and constellations. Because we used the same fields in successive years, many of these became very familiar; it seemed that the sky offered an order, peace, and constancy that made our world affairs seem petty. But in time, I realized that the universe is a rather wild place, full of collisions of asteroids, comets, stars, and molecular clouds. Worlds come and go there on a timescale so great as to be almost incomprehensible to us, and distances between most objects are so far as to be meaningless. Astronomy is a time machine that takes us back to beginnings; looking into space on our films gave me a sense of wonderment.

In 1987, Henry Holt, a retired planetary geologist with the USGS, joined Gene and me as a volunteer, part-time member of our observing team. When he expressed an interest in observing with us and came along for the first time, we found him to be a hard worker and congenial companion. What a luxury it was to have a third person with us on whom we could rely. At last we were able to develop our films throughout the night. We took turns guiding the telescope, changing film, and developing the exposures. I continued to be a part of those operations and also did all the scanning. Eventually, Holt was to take the summer runs on his own with students while Gene and I were away. Working with staff at Lowell Observatory in Flagstaff, Holt has found thousands of asteroids.

In 1989, we were joined by David Levy, who became a member of the PACS team for half of every year. Levy is a well-known amateur astronomer, author, lecturer, and educator. He became a reliable, capable, and loyal volunteer in our program. His infectious enthusiasm and sense of humor carried us through many a long night's observing. There is no doubt that our greatest discovery together, and in the whole program, was the discovery of Comet Shoemaker-Levy 9, the comet which had been pulled apart into 21 fragments by the gravity of Jupiter on a close pass in 1992, was discovered by us in 1993, and impacted Jupiter in 1994. What an adventure we had with that comet!

AUSTRALIAN CRATERS

Gene and I started another survey together in 1984, not astronomical but geological, on Australian craters, and we continued this program until his death in Australia in 1997. This survey was closely related to our "Mom and Pop" observing program, so called because the monetary support was very small and for a while the two of us were the only ones involved. Much of the year we looked up to find those objects that could collide with Earth in the future.

Then we took about three months in Australia to look down at the Earth to see where such objects had struck. The Australian continent has been stable, without a lot of mountain building and tectonic activity, which makes it perfect for the study of ancient rocks and impact structures. There are more meteorite craters (those with associated meteorites) in Australia than in any other country. We decided to look for undiscovered craters in Australia, as well as to do the work (mapping, gravity and magnetic studies, finding of meteorites and impact glass) on all the known craters where it had not been done before. During the years we were doing our crater work in Australia, most of the geologists there were involved with mapping and the search for mineral resources. This left an unoccupied niche in which we could work without treading on anyone's toes.

In order to do our field work, we purchased, after the first two years, a small Toyota Hilux 4-wheel drive pickup with sides and tailgate that let down for easy loading or unloading. We had two large plywood boxes constructed to hold all our gear: camping equipment and food; library; scientific instruments, including the alidade and tripod for mapping, theodolite for obtaining star positions and triangulating to get our own, magnetometer, and gravity meter; portable typewriter, stationery, and drafting supplies; and extra car parts, come-along and "roo" jack, and chains to get us out of difficult places. Two 50-gallon fuel drums were in front of the boxes and alongside, and at the end of the boxes, were ten 5-gallon water containers. We also carried, alongside, eight rubber doormats, ideal for getting us over sand dunes and out of creek beds. Eventually an electric air pump was installed under the hood of the Hilux for use in repairing the numerous flat tires we had each year (one year we had 23 within three months). Gene was an expert on changing and repairing tires when we were miles from anywhere. At the end of the field season, we would arrive back in the city of our departure (Perth, Canberra, or Adelaide), frequently with only four rather bad tires and no spare, despite having left for the field with at least three spares. For the first three years, while in the outback of Western Australia, we had a radio, installed in the pickup by Australia's Geological Survey. In 1996 and 1997, we carried a satellite phone and a GPS location finder. Needless to say, our pickup was one of the heaviest in the country, but our equipment and supplies made it safe and possible for us to spend three or four weeks deep in the outback with no one else around. We were down to basics, working from dawn to dark, with no regular telephone (on the satellite phone we could call out but no one could call us), no fax, no computer or word processor. We loved it.

Our trips to Australia provided some of our happiest and most rewarding times together. We were excited by all the exotic animals and the very different biota; the spring wildflower bloom must be one of the loveliest anywhere and we traveled among them for hours. We were delighted by the people, who seemed to us so very laid back, warm, and generous; we were enchanted by the beautiful, dark, starlit skies and would lie in our sleeping bags with binoculars to look at them together.

As the years progressed with our work in Australia, we had the opportunity to work on approximately 17 different craters and impact structures and checked out a large number of false hopes, which either were on the maps or were called to our attention by others. We came to know the country like the backs of our hands, and knew each and every track in most of Western Australia, Northern Territory, and South Australia, as well as many in Queensland and New South Wales. The friendships we made, with scientists, business people, professors, and station (ranch) people, were deep and lasting; even casual acquaintances would recognize us when we met them on a safari trip a long way from home. The appearance of our pickup certainly helped, but hardly any Australians would go out as we did, alone without several other vehicles along. People have often asked if we weren't worried by the dangers, but we always felt that if we were prepared for everything, there was nothing we could not handle together. There are no dangerous wild animals, we went in the winter when venomous snakes were not about, and we were well prepared to handle difficulties.

Tektite Studies

Another of our Australian projects involved the study of tektites. These small glassy objects are the result of an impact that throws the crater melt high into the atmosphere to come down across huge distances. Tektites and microtektites are found, for example, in relation to the huge Chicxulub crater event. They are found in many countries and in the ocean as the result of impacts at great distances. Australites are strewn across most of Australia and into the southern sea, having come from a structure, yet to be discovered, in or near Indochina. Gene and I spent a number of months with Ralph Uhlherr gathering information on tektites along the southern coast of Victoria, where Ralph had made a very large collection over time. This is a spectacular stretch of coastline, which draws numerous tourists every year. Personally, I was enchanted to work on something near the coast because I have always been drawn to the ocean, with its ever-changing moods, its crashing waves against the cliffs, its long sandy beaches. The cliffs are very high on this coast. Surely, this is one of the most spectacular places to do geologic field work, but it is also, to me, rather scary because we were working on slopes that plunged over cliffs a hundred feet high. Tektites were weathering out of a formation and working their way down the slopes.

THE FUTURE

In July of 1997, a head-on collision with another vehicle on a remote stretch of road, where commonly one might see only one or two other vehicles in a day, brought our adventures to an end with Gene's death and my injuries. Since the time of the accident, I have had to take stock of the direction of my life without Gene. Much of the Australian work remains for me to write up, along with the maps to complete. This work represents a huge investment of time and effort that should not have to be repeated but rather built upon by others. My big interest involving the discovery of planet-crossing asteroids and comets continues. At Lowell Observatory I am becoming involved with LONEOS (Lowell Near-Earth Object Survey), a project on a dedicated telescope near Flagstaff. Many objects on the films taken at Palomar in our PACS project remain to be worked on. And David Levy and I are continuing our comet search with his telescopes, both in Flagstaff in summer and in Tucson in winter.

I have watched delightedly the growing enthusiasm for asteroid and comet research, which has developed along with an increasing awareness of the hazards of impact on Earth. Today there are sky surveys capable of finding many thousands of asteroids and comets—something Gene and I saw the need of many years ago. I view these with some awe as I see the rates of discovery increase steadily. What a change this is from the years of the Palomar projects! An efficient vacuuming of the skies is underway, but I wonder if it is as much fun to those involved as the old-time astronomy I enjoyed so much. I rather doubt it. However, the feeling of accomplishment in a search that may someday save our home planet from great destruction will make up for it.

Impact remains an important focus of my attention with its many facets. Since the original hypothesis offered by Walter and Luis Alvarez in 1980 on asteroid or comet impact as a cause of the Cretaceous-Tertiary boundary event, there has been a gradual acceptance of impact cratering as new paradigm; our Earth bears the consequence of impact and some of the great extinctions of life have followed these. Large rocks and veritable mountains do fall out of the sky, a difficult concept for many geologists to accept; the effects of their impact on life are inescapable. The number of newly recognized impact craters increases by several each year. Some of them have been found as buried structures in the course of drilling programs. Gene and I found that although some characteristics of these structures are typical and almost always present, every structure is different and provides new knowledge about the complicated geologic effects of an impact. We've come a long way since the origin of Meteor Crater, Arizona was established and the whole study of impact began.

Planetary science as a field of knowledge, likewise, is growing steadily, and the more we know, the more questions arise to be answered. I have indeed been fortunate in adding a passion for science to my early enthusiasms. The learning process for both Gene and me was continual over our years together, and the challenge of trying to keep pace with developments on all fronts was a joy. Without Gene, I would never have known the excitement of planetary science nor have had the opportunities I did to work in that area; without me, he often said, his search for asteroids and comets and then the Australian cratering work would never have been attempted. Together, we could do more than either of us alone.

What more could I ask for as I go into the future? That question leads me to one more thought. Since the time of the accident in which I lost Gene, the awareness of our human need for others has dominated much of my thinking. Family and friends have been very important in my own recovery, and the concept of their importance, I discover, is as essential as the need for knowledge of our physical world. Without the human relationships we cherish, knowledge would count for naught; both are to be nourished. Henceforth, I'll continue my scientific exploration, knowing that I must not neglect the other side of living.

Acknowledgments

I am indebted to the U.S. Geological Survey, Caltech and Palomar Observatory, NASA, and Lowell Observatory for providing institutional support to Gene's and my efforts over the years. A large number of friends from these institutions and throughout the world, as well as my family, immediate and extended, have helped make possible the memorable and happy life that Gene and I shared together.